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STATUS OF POROUS TUBE PLANT GROWTH UNIT RESEARCH: DEVELOPMENT OF A PLANT NUTRIENT DELIVERY SYSTEM FOR SPACE

by

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SUMMARY:

A system being developed for plant production in space has been used to grow wheat, beans, rice, and white potatoes with varying degrees of success. Preliminary experiments indicate that the negative gauge pressure used to control the nutrient solution at the root/membrane interface and pore size affect plant production.

KEYWORDS:
Membrane, plants, nutrients, pressure.

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INTRODUCTION

One goal of the Controlled Ecological Life Support Systems (CELSS) Breadboard Project at the John F. Kennedy Space Center (KSC) is to bring together existing technologies and define needs for technology development for a controlled ecosystem to support space exploration. In a CELSS, materials (solids, liquids, and gases) are recycled with the addition of energy (electrical) to drive the processes with little need for addition of materials from outside the system. The four major components of CELSS are biomass (food) production, biomass processing, waste recycling, and ultimately the crew. As part of the food production component of a CELSS, methods for delivery of nutrients and water to the roots of plants are required, both under gravity (lunar and planetary colonization) and under microgravity (space station and planetary exploration). To accomplish the delivery of water and nutrients to plants under microgravity, the porous tube nutrient delivery system was developed. This system utilizes a concept proposed by Wright and Bausch (1984) of metering nutrient solution by capillary action, through a microporous, hydrophilic membrane to the roots of the plants in a very controlled manner.

This paper describes the steps taken to develop this concept into a system that supports plant growth on much larger scale for food production. Secondly, it is a review of the testing of configurations, pore size, materials, and different operating pressures and how these variables affect plant growth.

THE POROUS TUBE SYSTEM

The plant envelope

The initial work with the porous membrane system utilized small, flat plates to support the membrane and contain the nutrient solution. The first attempt to scale-up to crop production involved the development of the plant envelope, (Figure 1) which utilized Tufrin membrane (Gelman Sciences, Inc.)* heat-sealed to a vinyl backing on which manifolds were produced at opposite edges during the heat sealing process. Sandwiched between the vinyl and membrane were two layers of screening to allow fluid flow and fittings were attached to each manifold. Nutrient solution was pumped from a reservoir, through one manifold, traveled as a thin film beneath the membrane to the other manifold where it was drawn out by the pump and returned to the

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*The mention of a brand name does not imply endorsement of the product by The Bionetics Corp. or NASA or imply approval to the exclusion of other products that may be suitable.

reservoir. Problems with plant support, localized drying of the membrane, and maintaining membrane seal made redesign necessary even though wheat seed germinated and grew in the system.

The tubular membrane plant growth unit

The tubular membrane system (Figure 2) succeeded the membrane envelope. It utilized a more durable acryllic membrane (Versapor) than the envelope and was supported by an open tubular plastic framework. The membrane used in the tubular system typically had a pore size of 0.2 micrometers (um), but a membrane with a pore size of 5.0 (um) was also used. Utilizing standard PVC pipe and fittings, the tubular membrane plant growth units overcame the problems of plant support, local drying, and maintaining a good seal (Dreschel, et al. 1987).

The porous tube plant growth unit

To increase the longevity of the plant growth units, alternate hydrophilic, porous materials have been utilized in the porous tube plant growth units with minor modifications (Figures 3 and 4). The materials currently being utilized are hydrophilic porous polyethylene tubes (Porex) and cylindrical porous ceramic filters (Norton and Osmonics). These materials adequately replace the membrane and function in a similar manner. The latest design (Figure 4) also replaces the rigid outer cover with a black inside/white outside polyethylene wrap held rather loosely to the porous tube with a open tubular plastic support. The longitudinal edges of the polyethylene wrap form a double flap at the top to shade the porous tube but allow shoots to emerge into the light. The shading reduces direct evaporation and prevents algae growth on the porous tube surface.

Support equipment

The configuration of the initial tubular membrane systems consisted of a plant growth unit, pump, reservoir, and tubing to connect them (Figure 5). In each case, the negative gauge pressure holding the nutrient solution within the porous tube was dependent on the vertical distance between the solution level in the reservoir and the plant growth unit (probably ranging from 0.3 to greater than 4.0 kPa). Thus, although the solution was contained against gravity, the effect of gravity was still seen in the control of the negative solution pressure within the plant growth units.

The design of second generation of these nutrient delivery systems (Figure 6) included not only the (peristaltic) pump and reservoir, but incorporated a stand-pipe supplied by a pump from the reservoir and a control valve and vacuum gage to monitor the negative pressure. The stand-pipe system eliminates most of the pressure effects of drawing solution against gravity from the reservoir and delivers solution to the level of the plant growth units with nearly zero pressure. The negative pressure is produced by adjusting the valve upstream of the plant growth unit and can be monitored with the vacuum gauge as the peristaltic pump draws solution through the unit and returns it to the reservoir. Thus, the desired pressure can be set and monitored.

CROP TRIALS

Wheat

The initial test of the tubular membrane configuration was with wheat (Triticum aestivum cv. Yecora Rojo), involving two small units seeded directly, one with holes in the outer pipe and the other with a slot for shoot emergence. This first trial was successful in producing plants with seed production comparable to that expected in field-grown wheat (Bugbee and Salisbury, 1985). The second trial involved eight units, two of which were not maintained full cycle due to pump failure, so that six units were maintained to harvest. Seed production was lower in this trial than the first, probably due to a higher negative pressure on the nutrient solution and higher planting density. The third trial involved ten units, with yet lower seed production, again probably due to higher negative pressure and planting density. In each of these successive trials, the units were located higher than the nutrient reservoir than the previous, which would create a more negative solution pressure due to gravitational force.

The next three trials with wheat utilized the stand-pipe configuration, trial four utilizing nine membrane tube units with pressures controlled at three levels to give three treatments, replicated three times each. Trial five utilized nine porous polyethylene tube units, again with three pressure treatments. Trial six utilized 20 units, both membrane (pore size and pressure comparisons) and polyethylene tubes (configuration comparisons). These trials indicate an important role of pressure in good plant growth (less negative pressure supports greater growth). Pore size was also shown to have an effect (larger pore size supports greater growth) and some of the configurations (root containment structures) were shown to give greater growth (at least initially) so that plants in the other configurations were better able to compete for available light, the taller plants shading the shorter ones. Summary results of the wheat trials are presented in Table 1.

Rice

Two of the early membrane units were planted with rice (*Oryza sativa* cv. Lemont) and maintained for a full year. The plants matured and produced one crop of seed during this time, were cut back and produced new leaf growth. Although there was a large number of undeveloped seed, it was felt that there was some potential for growing rice crops in this system. Further work is required.

White potato

Two pairs of the polyethylene tube units were planted with white potatoes (*Solanum tuberosum* L. cv. Norland) and harvested at 64 days with tubers being produced. The first pair utilized a rigid pipe for root/tuber containment and the second pair utilized a closed-celled foam outer tube for root/tuber containment. The results of this trial is presented in Table 2 with results from Wheeler and Tibbitts (1987) of potatoes grown for 64 days in peat-vermiculite. Although environmental conditions were probably not identical between the porous tube unit grown potatoes and the peat-vermiculite-grown potatoes, the differences seen in the biomass produced probably could not be attributed to environmental differences, but more so to the method of nutrient delivery. Plants grown in the porous tube units were about one-tenth the size but had a harvest index as high or higher than the peat-vermiculite plants.

Lettuce

Lettuce (*Lactuca sativa* cv. Waldman's Green) was grown in the membrane tube units and compared to two other (gravity dependent) nutrient delivery techniques. In this study, the membrane-grown lettuce produced less biomass over time than those grown in the two gravity dependent systems (Bubenheim, et al. 1987). A lettuce trial utilizing 20 units, including membrane, polyethylene and ceramic units, showed pressure effect trends similar to that seen in wheat. In addition, some differences in plant growth on the different materials and in different configurations at similar pressures was observed. Summary results of this trial are presented in Table 3.

Beans

Beans (*Phaseolus vulgaris*) were grown in the second tubular membrane trial with pods and seed produced. Currently, beans are being grown on porous ceramic tubes and will be used for water potential measurements with different solution pressure treatments.

CONCLUSIONS

A number of crop plant species have been grown in the porous tube system with varying degrees of success as to total and edible biomass produced compared to field-grown or standard hydroponic methods. Wheat, rice, beans, and lettuce can probably be grown (using more accurate solution pressure and optimal environmental conditions) with production values near to plants grown in other media. Potato growth appears to be stunted, which may be a response to root restriction.

FUTURE FOCUS OF WORK

The trials described above indicate that this system may have some potential utility as a cultural tool in plant water stress research as well as use as a nutrient delivery system for space experimentation with plants and eventually for space crop production. Continued work is forseen on defining pressure effects on the growth and water status of plants. The testing of different configurations will continue in order to improve nutrient delivery and to adapt the system to a variety of plant species. Automated nutrient monitoring of pressure, reservoir liquid level, pH, electrical conductivity, and temperature are now in development with all but solution pressure and temperature being controlled. Development of flight hardware will allow testing of the porous substrate technique under space flight conditions and indicate where futher improvement or development is needed.

LITERATURE CITED

Bubenheim, D. L., T. W. Dreschel, and C. A. Mitchell. 1987. Comparison of plant growth in a tubular membrane hydroponic system with that in conventional hydroponic culture. Hortscience 22:1051 (abstr.).

Bugbee, B. G. and F. B. Salisbury. 1985. Wheat production in the controlled environments of space. Utah Science: Winter, 1985.

Dreschel, T. W., R. P. Prince, C. R. Hinkle, and W. M. Knott. 1987. Porous membrane utilization in plant nutrient delivery. Paper #87-4025, Amer. Soc. Agric. Eng., Baltimore, MD.

Wheeler, R. M. and T. W. Tibbitts. 1987. Utilization of potatoes for life support systems in space. III. Productivity at successive harvest dates under 12-h and 24-h photoperiods. Amer. Potato J. 64:311-320.

Wright, B. D. and W. C. Bausch. 1984. A plant growth system for orbital plant experiments. Paper #84-2524, Amer. Soc. Agric. Eng., New Orleans, LA.

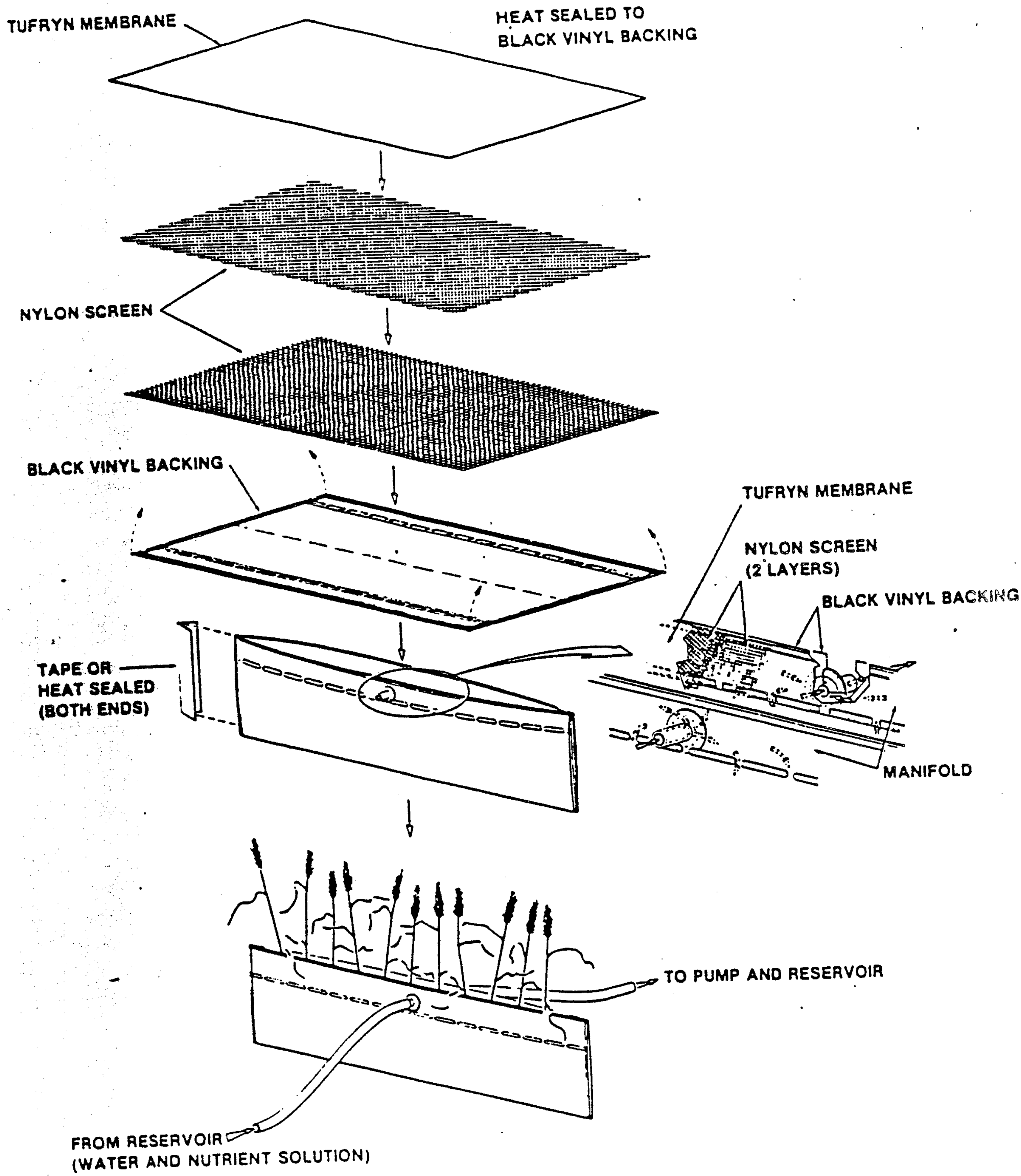

Figure 1. Schematic of the plant envelope for nutrient delivery.

Tubular membrane plant growth unit

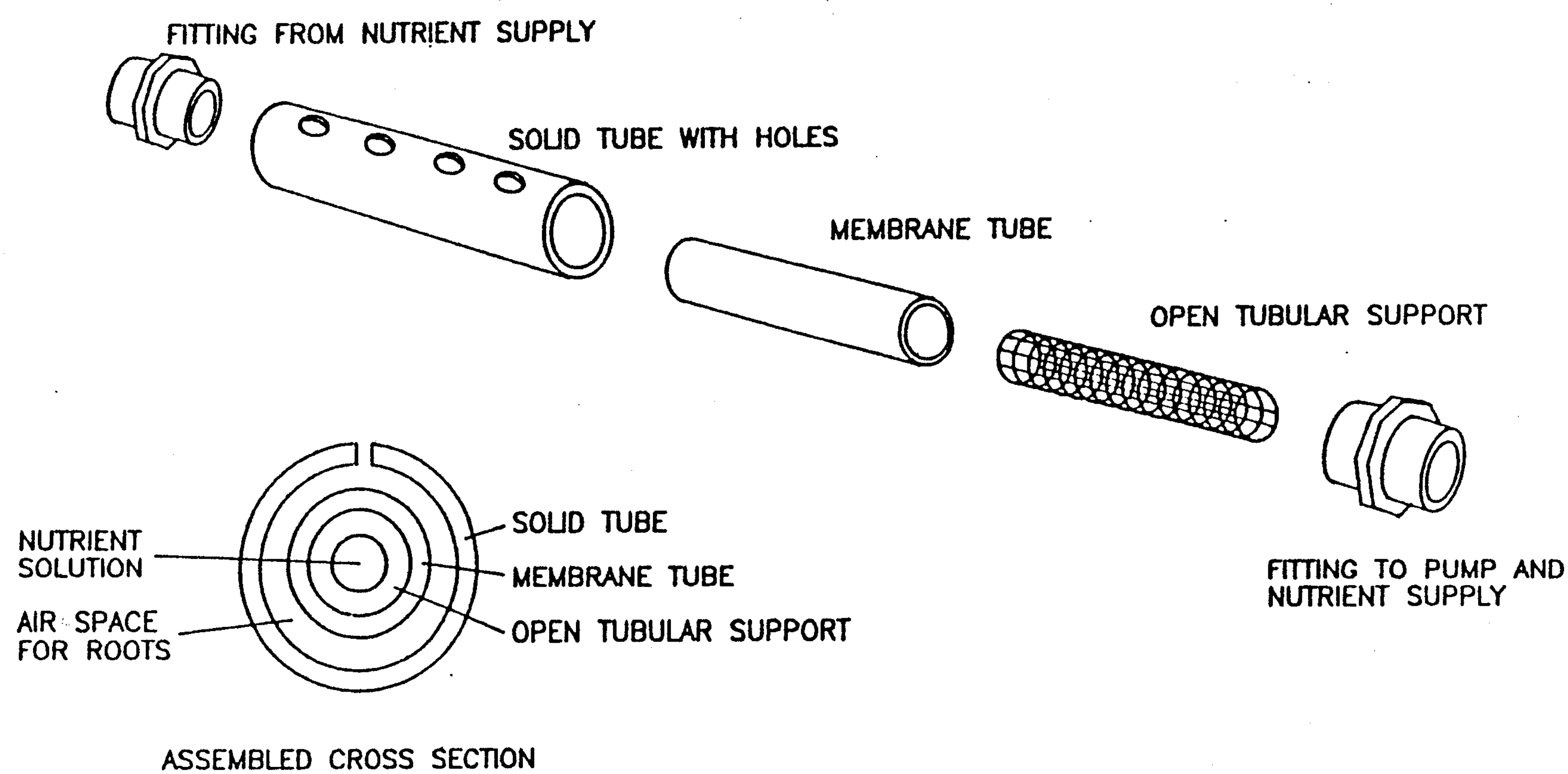

Figure 2. Schematic diagram of the tubular membrane plant growth unit (original design)

Porous tube plant growth unit

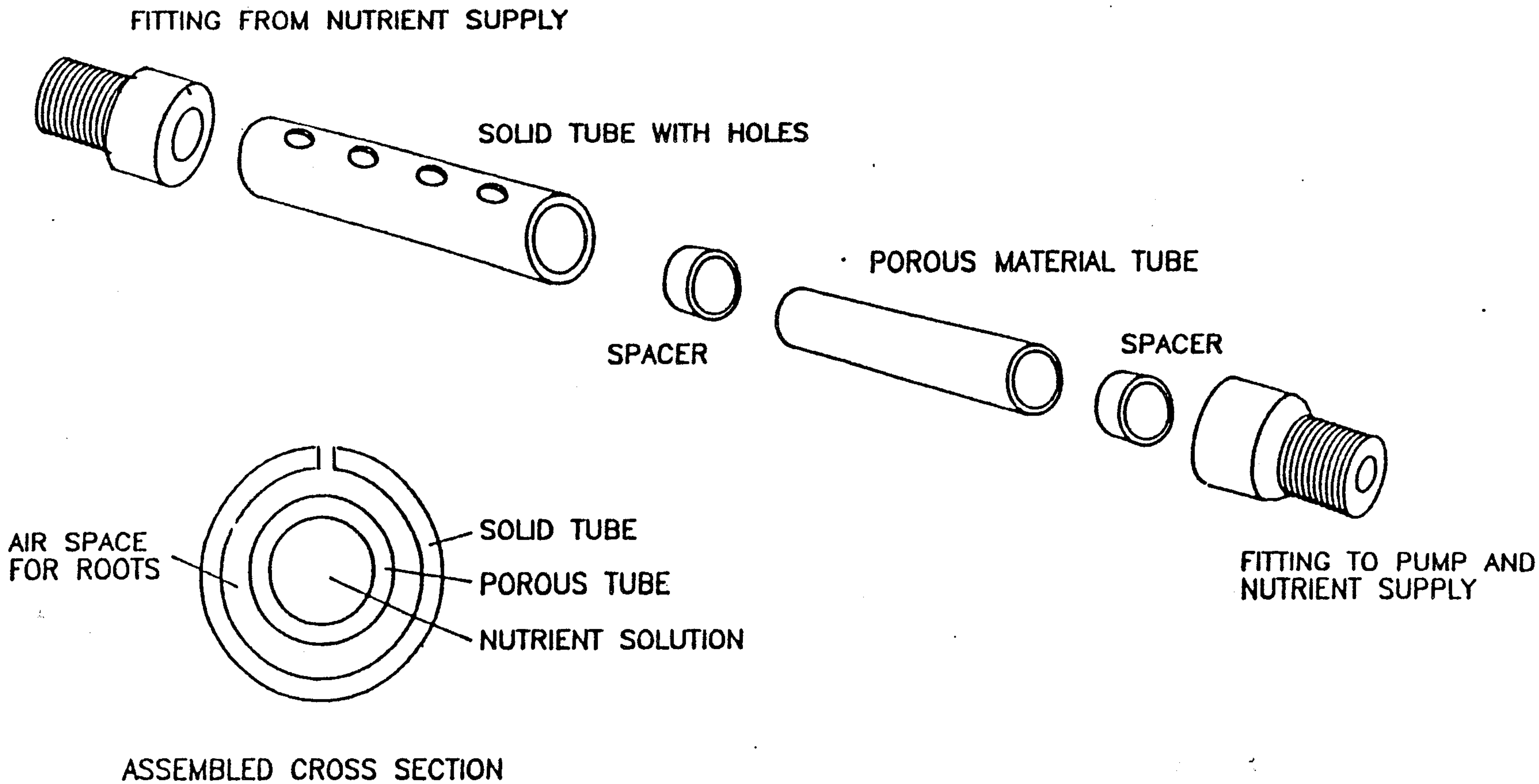

Figure 3. Schematic of the first design of the porous tube plant growth unit.

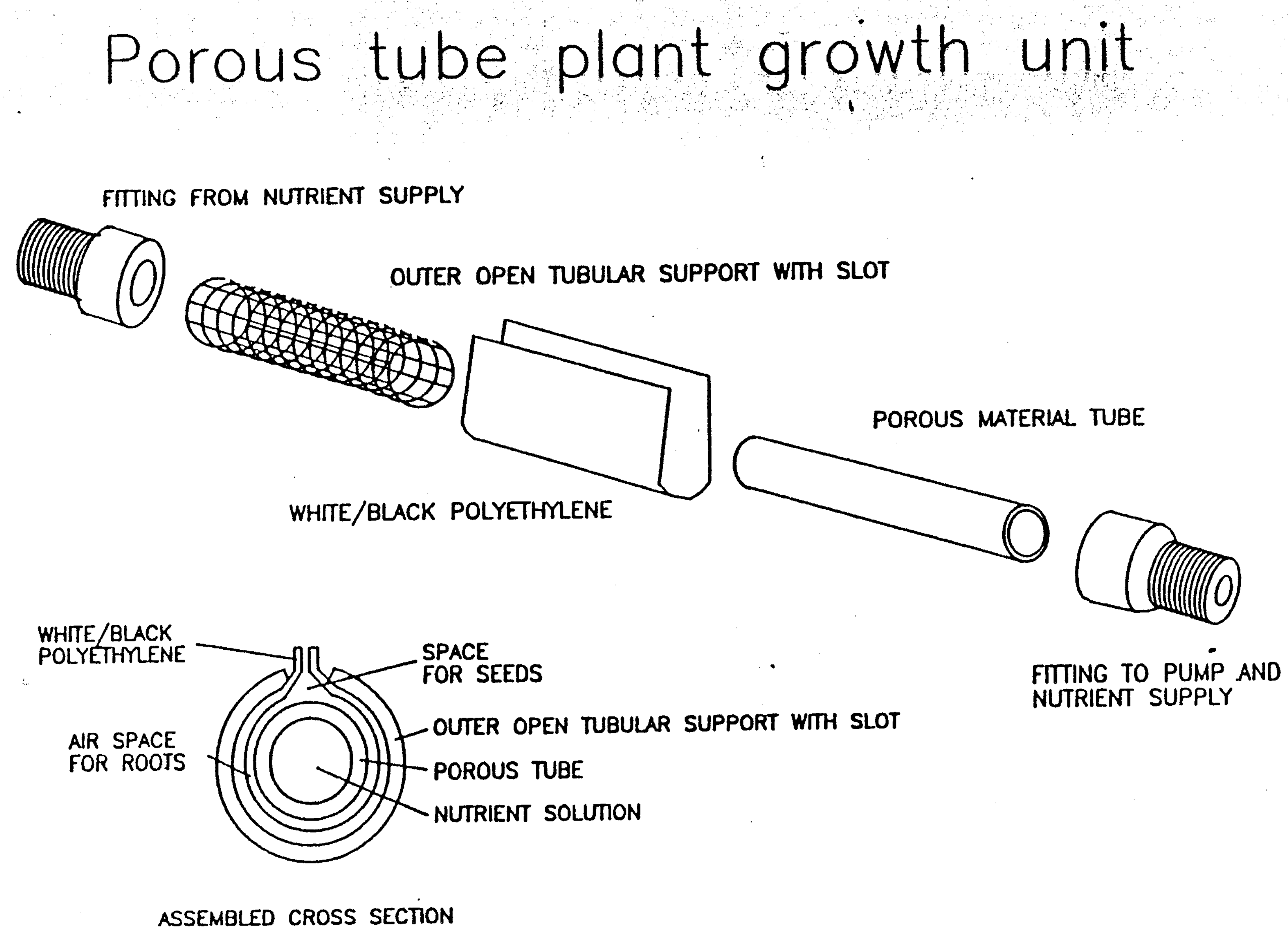

Figure 4. Schematic diagram of the second design of the porous tube plant growth unit.

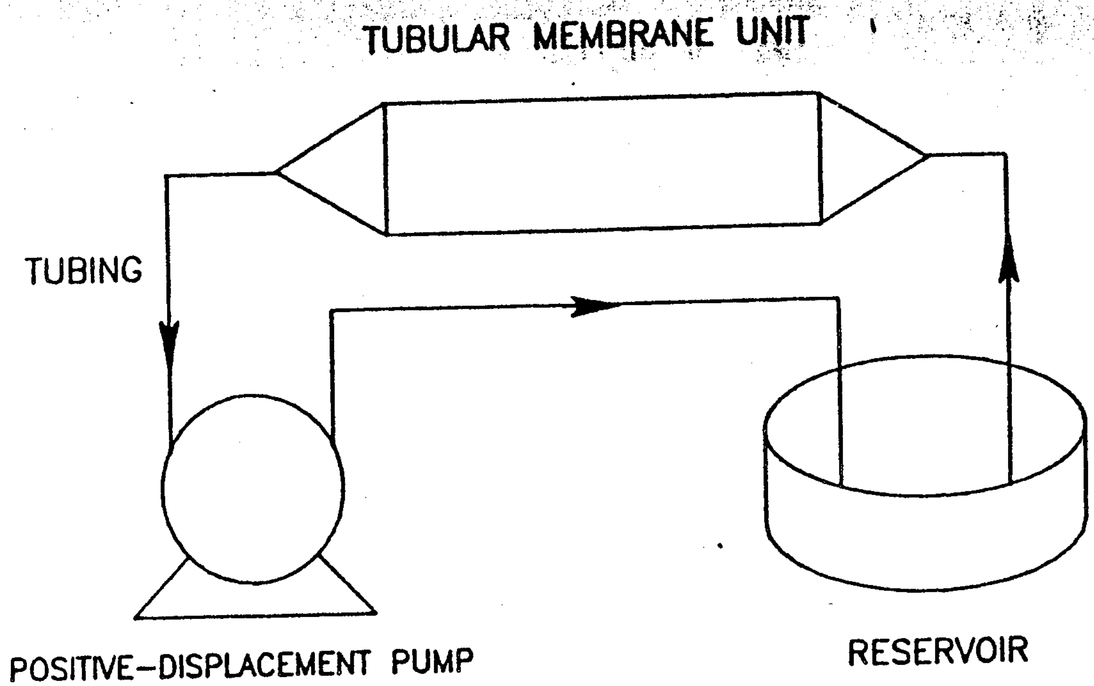

Figure 5. Schematic diagram of the original tubular membrane/porous tube nutrient delivery system.

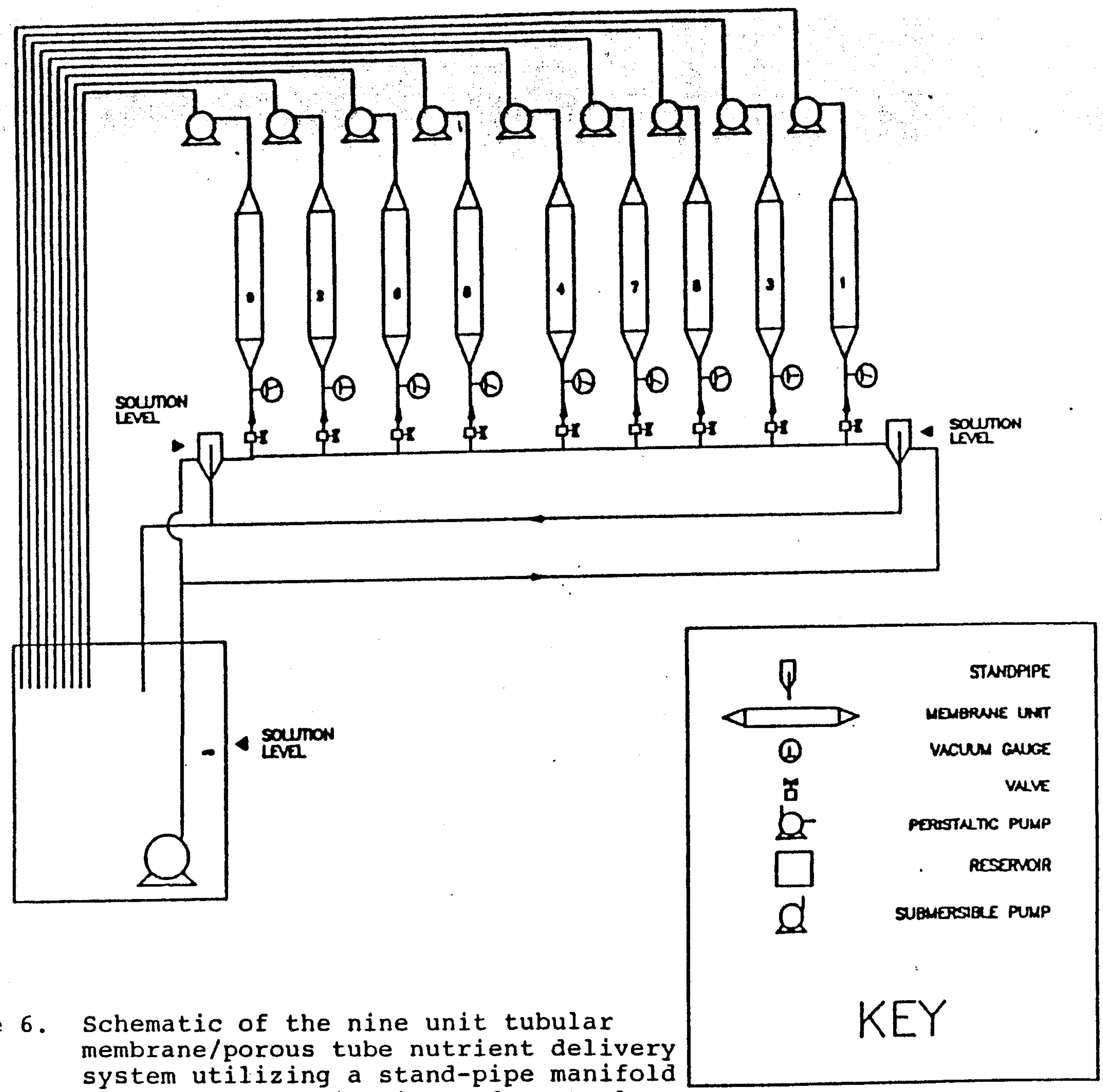

Figure 6. Schematic of the nine unit tubular membrane/porous tube nutrient delivery system utilizing a stand-pipe manifold and pressure monitoring and control.

Table 1. Summary harvest results from the first six tubular membrane/porous tube unit wheat trials.

Trial#/ tube*	Treat- ment	Grams total mass/plant (dry)	Grams seed mass/plant (dry)
1/m	-	4.28	2.43
2/m	-	2.28	1.05
3/m	-	0.68	0.32
4/m	-0.45 kPa	3.01	1.53
4/m	-0.85 kPa	2.40	1.18
4/m	-1.70 kPa	2.37	1.19
5/p	-0.45 kPa	3.28	1.72
5/p	-1.48 kPa	1.89	0.91
5/p	-2.58 kPa	1.83	0.90
6/m	-0.40 kPa	2.48	1.07
6/m	-1.50 kPa	1.88	0.82
6/m	-3.00 kPa	1.55	0.66
6/m	0.2 um pore	2.48	1.07
6/m	5.0 um pore	5.40	2.85

* m=membrane tube, p=porous polyethylene tube.

Table 2. Summary harvest data from the first two potato trials, the first with a rigid outer containment tube and the second with a flexible (closed celled foam) outer containment tube, compared to potatoes grown in peat-vermiculite media.

Trial	Grams total mass/plant (dry)	Grams tuber mass/plant (dry)
Rigid tube #1*	8.6	4.3
Rigid tube #2*	10.5	5.9
Flexible tube #1*	2.9	2.1
Flexible tube #2*	14.1	9.8
Peat-verm #1**	121	62
Peat-verm #2***	228	114

*Tube=porous polyethylene tube units, 18-h photoperiod, 1 plant each.

**Peat-Verm#1=peat-vermiculite medium, 12-h photoperiod, 4 plant average (Wheeler and Tibbitts 1987).

***Peat-Verm#2=peat-vermiculite medium, 24-h photoperiod, 4 plant average (Wheeler and Tibbitts 1987).

Table 3. Summary harvest data of the tubular membrane/porous tube lettuce trial (25 days).

Pressure/tube/ configuration*	Grams total mass/plant (dry)	Grams head mass/plant (dry)
-0.2 kPa/p/4	0.79	0.62
-0.3 kPa/p/4	0.38	0.28
-1.2 kPa/p/4	0.13	0.09
-0.3 kPa/c/4	0.70	0.62
-0.4 kPa/m/2	0.78	0.60
-0.4 kPa/p/3	0.20	0.15

*Tube: p=porous polyethylene tube; c=porous ceramic tube; and m=membrane tube. Configuration: 2=refer to Figure 2; 3=refer to Figure 3; and 4= refer to Figure 4.